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ATMOSPHERIC ATTENUATION OF NEAR INFRARED  
RADIATION PROPAGATING THROUGH FOG

by

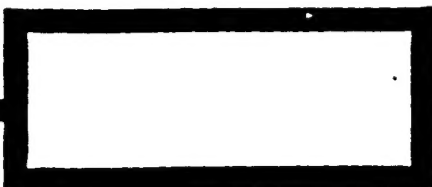
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# ATMOSPHERIC ATTENUATION OF NEAR INFRARED RADIATION PROPAGATING THROUGH FOG

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## ABSTRACT:

In the light of the measurement data in real atmosphere, the attenuation properties of near infrared radiation of GaAs LED propagating through fog are discussed. Comparisons of the attenuation coefficient with the simultaneously observed meteorological visibility show that there is a close relationship between them. This conclusion is proved by the theoretical calculation.

## I. Introduction

Attenuation of GaAs near infrared radiation in the atmosphere, especially in fog, is a very interesting problem to many infrared engineering researchers. Some researchers have attained some results [1]. Many tests were conducted by the authors at Qingdao and Huangshan Mountains. As revealed in the results, there is a close relationship between attenuation coefficient and atmospheric visibility. The relationship can be appropriately described by the Koschmieder formula [2]. The conclusion has been verified by measurements at different periods at same or different sites, and by theoretical calculations by using cloud and fog data at the Lushan Mountains [3].

## II. Measurements

### 1. General situation

The measurement equipment is divided into two portions: emission and receiving. The emitting terminal is composed of an emitting telescope, a GaAs light emitting diode (LED), as well as modulating and steady-current circuits. The receiving terminal is composed of a receiving telescope, a pre-amplification stage, a frequency-selecting stage, phase-sensitive wave detection, gain control and a computer. The emitting-receiving telescope is a nonspherical object lens with aperture  $\phi=116\text{mm}$ , focal length  $f=177.1\text{mm}$ , and visual field approximately  $14\text{mrad}$ . The effective emitting power of the LED is  $10\text{mW}$  (including consumed power of optical components). The maximum effective power that the receiving terminal can receive is  $50\mu\text{W}$ ; the activity range of the receiving system is  $80\text{dB}$ . If two terminals are  $100\text{m}$  apart, the equipment can measure radiation with transmissibility as low as  $5 \times 10^{-5}$ . After demodulation with frequency selection, the receiving signals are sampled by a microcomputer with an A/D converter for 10 seconds of sampling at 10 samplings per second. Finally, computation is conducted according to the following equation:

$$\mu = -\ln(I/I_0)/L \quad (1)$$

In the equation,  $L$  is the distance between two terminals;  $I$  is signal intensity thus measured;  $I_0$  is signal radiation when visibility is greater than  $40\text{km}$ . The computation results are outputted in real time by a printer.

During measurement, one sampling is conducted for every two (or four) minutes. Measurements of target sensitivity and sampling are conducted simultaneously, coordinated by a meteorology station located in the experimenting area. However,

as restricted by terrain, it was not possible to establish appropriate markings as required for reference, therefore errors of visually measuring visibility are relatively high. Generally the visibility is determined and verified by two or more testing personnel.

Experiments were conducted at Qingdao in July 1985, and at Huangshan Mountains in the period of September through October in 1985, mainly to measure atmospheric attenuations when there was sea fog. Two terminals of equipment were 165m apart; the underlying plane of the optical path is the sea beach. The experimental sites at Huangshan Mountains were Guangming Peak and Fucun Village below the mountain. The experimental distance at Guangming Peak was 94m. The emitting terminal was sited at Liandanfeng Peak while the receiving terminal was sited at an on-shift room in third floor of the meteorological station. The experimental distance at Fucun Village was 100m as the optical path was along a creek.

## 2. Measurement results

There were two occasions of dense sea fog during experiments at Qingdao between 06.30 and 16.00 hours on July 6, and between 06.30 and 13.00 hours on July 9. Fog moved past the optical path on the sea, mainly cluster shaped with moderate development throughout the period. Figure 1 shows variation of attenuation coefficient with time; the dotted line is the measured attenuation coefficient while the solid line is derived from the improved Koschmieder formula [2].

$$\mu = 3.912/V_M (\lambda/0.55)^{-0.5857V_M^2} \quad (2)$$

Deduced from the visually measured visibility  $V_M$  (km),  $\lambda$  is wavelength ( $\mu\text{m}$ ) in the equation. From Fig. 1, both variation trends are quite consistent, and the quantitative relationship is also relatively consistent.

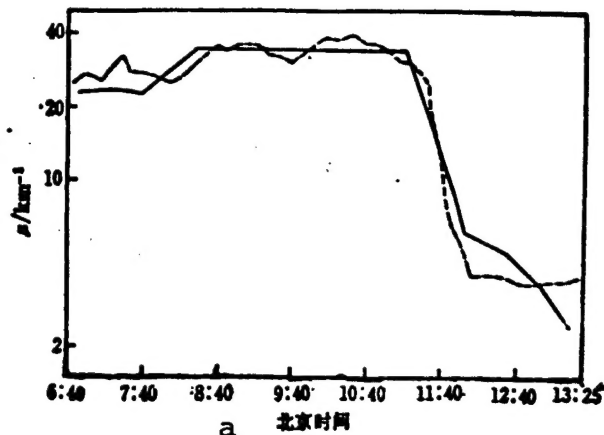


Fig. 1 The attenuation coefficient of sea fog as a function of time (July 9, 1985, Qingdao).

Key: a - Beijing time

Figure 2 shows the typical measurement results at experiments on Huangshan Mountains. With density changing abruptly with time, the fog on the mountain is actually a cloud as seen from the ground. In the period between 12.50 and 14.30 hours as shown in the figure, drizzle formed from large fog drops so measurement was suspended. Between 15.50 and 16.40 hours, signals were suspended as the fog became very dense. Measured at Fucun Village below the mountain was morning radiation fog with steady denseness. Ranges of attenuation and variation are similar to that of sea fog at Qingdao.

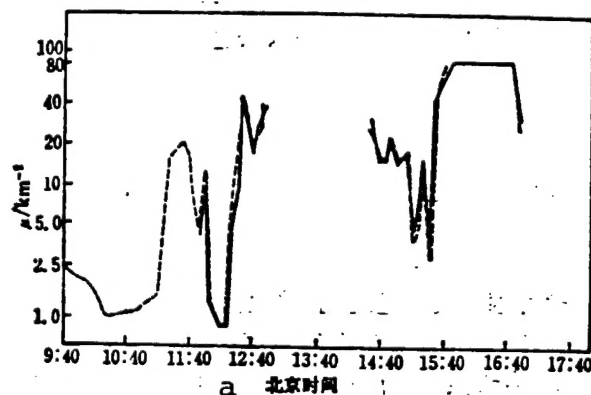


Fig. 2 The attenuation coefficient of Mount Huang Shan fog as a function of time (Sept. 27, 1985)

Key: a. Beijing time.

Up to 1000 data were obtained in both experiments. Most data match with the measured visibility. From Figs. 1 and 2, the correlation between attenuation coefficient and visibility is relatively consistent. As statistically revealed by all data, the correlation coefficient is upwards of 0.9.

Figure 3 shows the comparison of mean values of the measured attenuation coefficient ( $\mu_{exp}$ ) at different time periods at same (or different) site. The theoretical value  $\mu_{cal}$  of attenuation coefficient is derived from equation (2). We can see that generally speaking these measurement results are quite consistent with the Koschmieder formula.

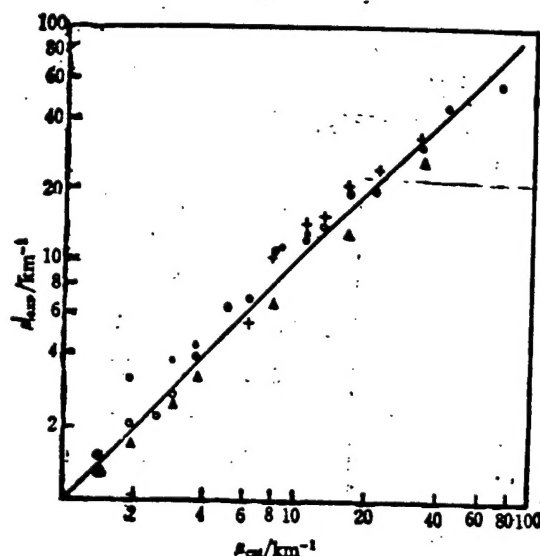


Fig. 3 Comparison of theoretical and experimental attenuation coefficient.  
 O—present measurement  $\Delta$ —Grimm<sup>[3]</sup> ●—Deng Benda et al., 1968, Beijing  
 +—Wang Dinghua et al., 1975, Qingdao

### III. Discussions

To explain the problem further, the authors discuss it theoretically.



Fog attenuation of various radiations can be calculated in principle based on the Mie scattering theory with respect to a certain fog crystal spectrum. The general expression equation of attenuation coefficient is

$$\mu = \pi \times 10^{-8} \int_0^{\infty} Q_m(m, r, \lambda) n(r) r^2 dr \quad (3)$$

In the equation,  $Q_m(m, r, \lambda)$  is attenuation efficiency factor, which is a function of complex refractive index  $m$ , particle radius  $r(\mu\text{m})$  and radiation wavelength  $\lambda(\mu\text{m})$ ;  $n(r)$  is the number of particles ( $\text{cm}^{-3}\mu\text{m}^{-3}$ ) when radius of unit volume is between  $r+1/2 dr$  and  $r-1/2 dr$ . The exact formula of attenuation efficiency factor has been given by Mie. However, since the radius of fog crystals is generally between 1 and  $10\mu\text{m}$  with its dimension coefficient  $x = \frac{2\pi r}{\lambda} > 1$ , generally  $Q_m(m, r, \lambda)$  can be calculated by using the approximate method provided by Deirmendjian [4].

The mostly used model of dimension distribution is  $\Gamma$  distribution:

$$n(r) = ar^b \exp(-cr); \quad (4)$$

In the equation,  $a$ ,  $b$  and  $c$  are fitting parameters. As revealed in actual observation, equation (4) can be applied to obtain better fitting effect [5]. In this model, various fitting parameters can be derived from easily measured macroscopic physical quantities, such as modal radius  $r_m(\mu\text{m})$ , particle number density  $N(\text{cm}^{-3})$  and water content  $W(\text{g}/\text{cm}^3)$  in unit volume. Based on definition of these physical quantities and equation (4), we can prove the following

$$a = Nc^{(b+1)} / \Gamma(b+1); \quad (5)$$

$$c = b/r_m; \quad (6)$$

Value of  $b$  can be derived from the following equation

$$f(b) = \left( \frac{8W}{4\pi N \rho r_m^2} - 1 \right) b^2 - 6b^3 - 11b - 6, \quad (7)$$

In the equation,  $\Gamma(x)$  is Gamma function, and  $\rho$  is water density (1 g/cm<sup>3</sup>).

Reference [3] provides in detail the data of cloud and fog on the Lushan Mountains. Thus, calculations are conducted by the authors. In the calculations,  $\lambda_1=0.55\mu\text{m}$ ,  $\lambda_2=0.9\mu\text{m}$ . The complex refractive indexes are,  $m_1=332-1.96 \times 10^{-9}i$ , and  $m_2=1.32-4.86 \times 10^{-7}$ , respectively [6]. Refer to Table 1 where only one half of data are listed. In Fig. 4, comparisons between calculated  $\mu(0.55\mu\text{m})$  and measured values of visibility are shown. The curve in Fig. 4 is plotted based on equation (2). From the figure, although variation of the fog crystal spectrum is on the high side yet the mean value of attenuation coefficient is still, more or less, consistent to the estimation given by the Koschmieder formula. Besides, from the fact that the vast majority of ratio  $R=\mu(0.55\mu\text{m})/\mu(0.9)$  of attenuation coefficients in two wavelengths are greater than 0.96, the attenuation coefficient at 0.9 $\mu\text{m}$  wavelength is still consistent with the above-mentioned conclusion. However, we should note that ratio here is a constant smaller than 1 with little variation. However,  $R$  estimated by equation (2) should be greater than 1 and varies with visibility rule. This apparently reveals that fog attenuation described with visibility has certain limitations.

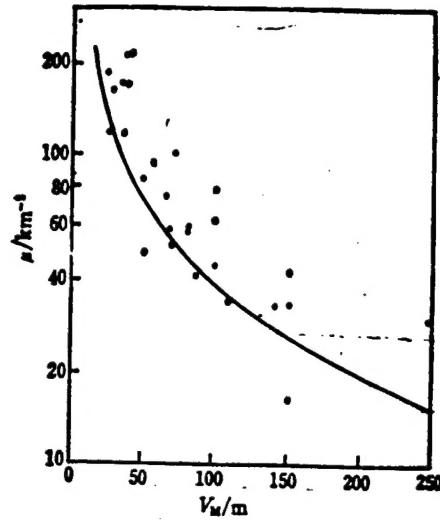


Fig. 4 The attenuation coefficient as a function of meteorological visibility.

Table 1 The parameters of fog distribution and attenuation coefficients

$r_m$ ( $\mu m$ )	$N$ ( $cm^{-3}$ )	$W$ ( $gcm^{-3}$ )	$a$	$b$	$c$	$V_m$ (m) ( $\frac{m}{s}$ )	$\mu(0.55)$ ( $km^{-1}$ )	$\frac{\mu(0.55)}{\mu(0.9)}$
1.75	182.9	0.76	25.7865	0.3941	0.2253	70	588.0	0.984
1.75	86.5	0.23	14.4973	0.484	0.3766	260	230.6	0.9805
1.8	686.8	0.07	976.6398	3.1724	1.7625	250	312.9	0.957
3.5	99.7	0.33	8.4924	1.1517	0.3291	110	350.6	0.9862
3.6	507.6	0.15	4.7582	13.387	3.7186	70	527.9	0.9761
3.6	574.3	0.19	11.2577	10.2853	3.857	100	633.0	0.977
3.6	97.1	0.055	6.2483	4.5774	1.2715	>200	142.2	0.9817
3.6	307.9	1.3	24.1379	1.057	0.2936	37	1173.7	0.975
5.25	144.8	0.15	0.0454	10.0836	1.9207	150	337.6	0.985
5.25	236.0	0.45	2.2923	4.1819	0.7965	65	745.2	0.97
5.4	493.2	1.9	10.4958	2.401	0.4446	40	2159.0	0.9812
5.4	492.9	1.3	6.7060	3.2974	0.6106	27	1877.1	0.9957
5.4	332.1	0.85	0.0274	11.6846	2.1638	80	790.6	0.9851
7.2	272.1	1.75	1.1515	3.2132	0.4463	30	1646.4	0.9961

Key: a - Measured

As mentioned above, the authors attain the following conclusions:

1. Fog attenuation is quite high. When the visibility is less than 100m, the attenuation coefficient of  $0.9\mu\text{m}$  radiation can be as high as  $30\text{km}^{-1}$  or above. Or, the 1km transmissibility is lower than  $10^{-13}$ .

2. Generally speaking, the Koschmieder formula is correct without apparent problem in engineering applications.

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